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PITCH DAMPING TESTS OF THE M823 RESEARCH STORE WITH CRUCIFORM AND SPLIT-SKIRT STABILIZERS

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UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

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Aerodynamics Research Report 246

PITCH DAMPING TESTS OF THE M823 RESEARCH STORE WITH CRUCIFORM AND SPLIT-SKIRT STABILIZERS

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ABSTRACT: The M823 configuration is an instrumented free fall store used in bomb stability research programs. This report presents the results of the pitch damping wind tunnel tests of the basic M823 forebody to which cruciform and split-skirt stabilizers have been attached.

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The purpose of this investigation was to measure the damping-in-pitch derivative of the M823 configuration with cruciform and split-skirt stabilizers.

The project was performed at the request of the Bureau of Naval Weapons under Task Number 42-005/212-1/F008-09-01.

The authors wish to acknowledge the assistance rendered by Mr. M. Hardy in report preparation.

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Captain, USN
Commander

K R Enkenhus

K. R. ENKENHUS
By direction

CONTENTS

ILLUSTRATIONS

INTRODUCTION

The U. S. Naval Ordnance Laboratory (NOL) has engaged in a cooperative bomb research program with the British Royal Aircraft Establishment (RAE) and the Australian Weapons Research Establishment (WRE). This effort was primarily undertaken to ascertain the suitability of six-degree-of-freedom digital computer programs for predicting the motion of free fall weapons.

A study of this type became feasible when it was learned of the instrumented bomb research program of the Weapons Research Establishment. As a result of joint meetings among representatives of NOL, WRE and RAE, a mutual research effort was agreed upon. The U. S. Naval Ordnance Laboratory agreed to perform the required wind tunnel measurements and some of the trajectory computations. The British and Australian laboratories agreed to make available various instrumented bombs for the free fall portion of the study.

In addition to comparing the digital computer trajectory calculations with the data obtained from the instrumented free fall stores, it was also decided to extend this cooperative effort to a study of less conventional stabilizers. These stabilizers would include free-spinning cruciform tails, free-spinning monoplane tails and split-skirt tails.

This report presents the results of pitch damping wind tunnel measurements of fixed cruciform and split-skirt tails. Other reports will present static and Magnus measurements on the various configurations.

SYMBOLS

C_m	Pitching Moment Coefficient, M_y/QAd
$C_{m_q} + C_{m_{\dot{\alpha}}}$	Pitch Damping Derivative, $\partial C_m/\partial(qd/2V) + \partial C_m/\partial(\dot{\alpha}d/2V)$
d	Reference Length, Maximum Body Diameter
I_y	Transverse Moment of Inertia
M_y	Pitching Moment (about the y axis)
p	Pressure
Q	Dynamic Pressure

q	Pitch Rate
S	Reference Area, $\pi d^2/4$
t	Time
T	Temperature
V	Free-stream Air Speed
x	Body axis colinear with the longitudinal axis of the store
y	Body axis normal to the longitudinal axis and in a plane defined by two opposing fins
z	Body axis forming a right-hand triad with the x, y axes
α	Angle of Attack
δ	Fin Cant Angle
ρ	Density of Fluid Medium
ϕ	Roll Angle
μ	Viscosity
γ	Ratio of Specific Heats

DESCRIPTION OF BOMB CONFIGURATIONS

The table below lists the various configurations that are included in the complete test program. In the case of the cruciform and the monoplane tails, the literal designation is followed by a symbol to indicate the angle of fin cant. Thus the symbol Bδ4 refers to a free-spinning cruciform tail with a four degree fin cant.

A. Fixed cruciform tail; δ = 0, 2, 4 degrees
B. Free-spinning cruciform tail; δ = 2, 4 degrees
C. Fixed split-skirt tail; skirt angle 10 degrees
D. Free-spinning split-skirt tail; skirt angle 10 degrees
E. Fixed split-skirt tail; skirt angle 15 degrees
F. Free-spinning split-skirt tail; skirt angle 15 degrees
G. Free-spinning monoplane tail; δ = 2, 4 degrees

The pitch damping measurements for configurations A, B, C and E are presented in this report. Data from static tests on configurations A, B and G are given in reference (1), and on configurations C and E in reference (2). Measurements on configurations D and F have not been made.

The wind tunnel models discussed in this report are illustrated in Figure 1. The upper figure is the M823 Research Store with a cruciform tail. This tail can be rigidly fixed to the body, resulting in configurations Aδ0, Aδ2 or Aδ4, depending on whether the fin is canted 0, 2 or 4 degrees. When a retaining screw is removed, the stabilizer is free to spin about the bomb's longitudinal axis. This configuration is designated Bδ2 or Bδ4, depending again on whether the fin is canted 2 or 4 degrees.

Shown in the lower part of Figure 1 is the M823 Research Store with a fixed, four petal split skirt. This is designated as configuration C, if the angle between a petal and the bomb's longitudinal axis is 10 degrees, or configuration E, if this angle is 15 degrees.

The wind tunnel model used in these tests was 1/10 scale. A line drawing of configuration A with appropriate dimensions is illustrated in Figure 2. A similar illustration of configuration C is presented in Figure 3.

In this investigation configurations A, C and E were tested at roll angles of 0, 22.5 and 45 degrees. A positive roll angle is defined as a clockwise rotation of the model when viewed from the rear along the longitudinal axis. The rear view orientation of the cruciform and split-skirt configurations at these three roll angles is illustrated in Figure 4.

EXPERIMENTAL METHOD

The wind tunnel in which tests tests were carried out was the Naval Ordnance Laboratory's Supersonic Tunnel No. 1. This facility is a blowdown wind tunnel having stagnation conditions of one atmosphere. Although neither equivalent altitude nor Reynolds number can be controlled in this facility, it is of interest to know these quantities as a function of tunnel Mach number.

The equivalent-density altitude, assuming an isothermal atmosphere, can be expressed as a function of Mach number by the relationship,

$$h = \frac{5RT_o}{2} \ln\left(1 + \frac{M^2}{5}\right) , \tag{1}$$

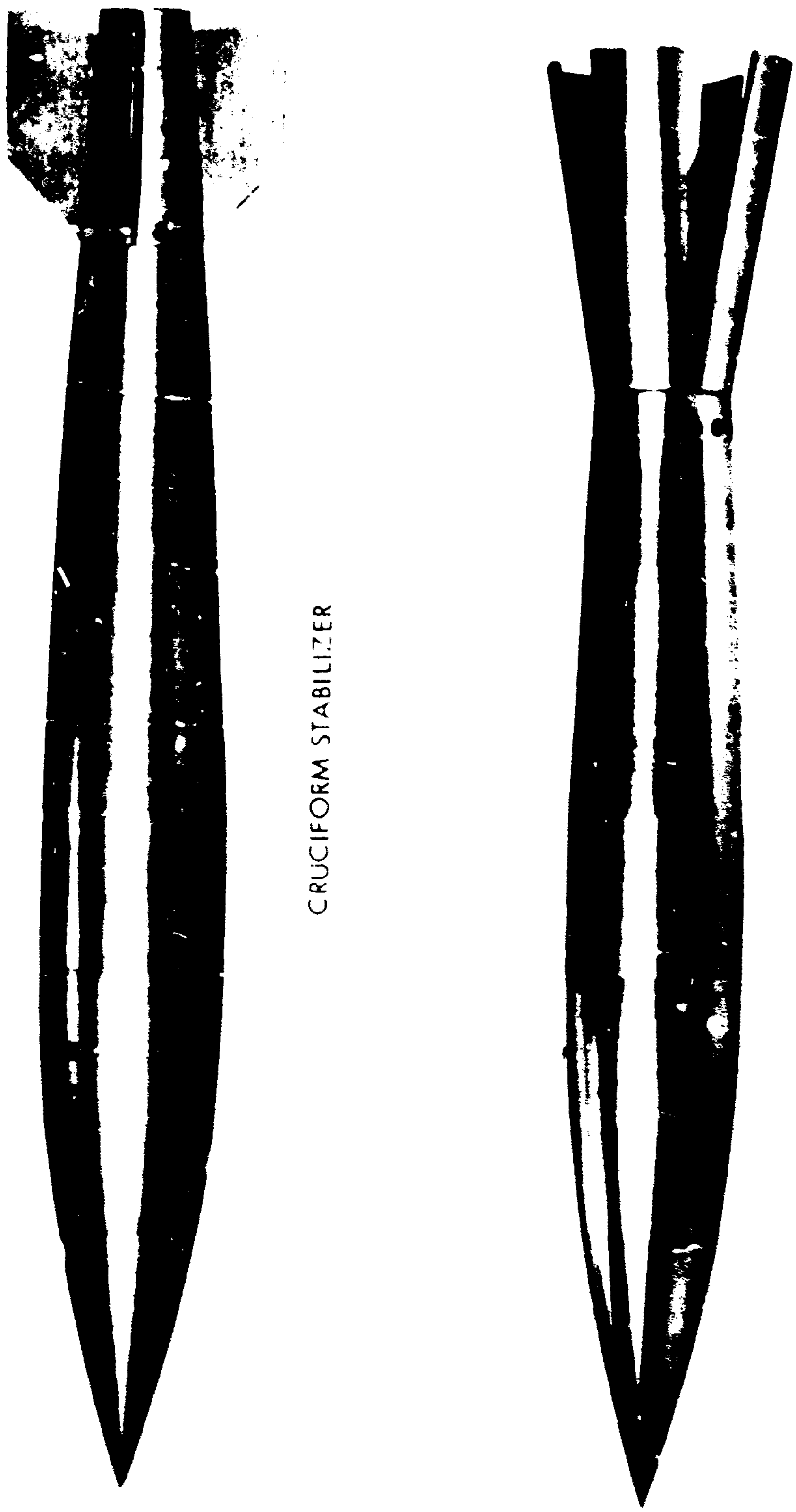


FIG. 1 WIND TUNNEL MODELS OF M823 RESEARCH STORES

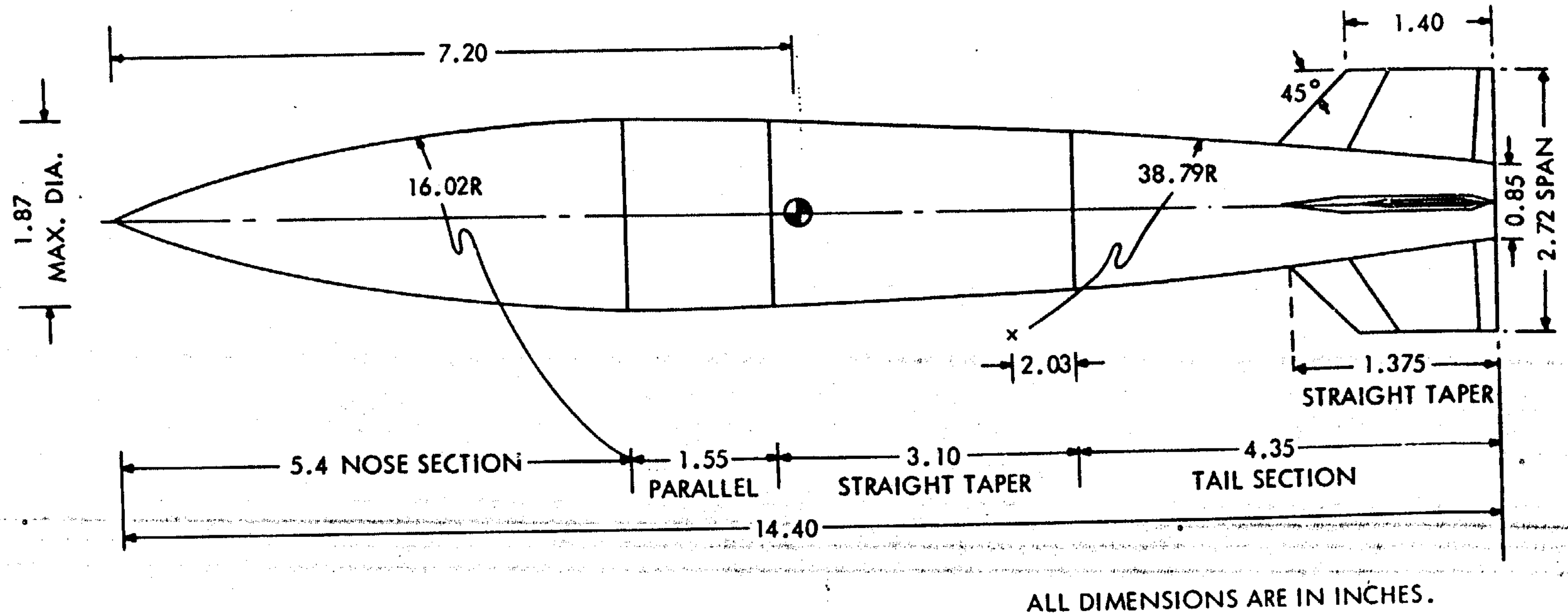


FIG. 2 M823 RESEARCH STORE WITH CRUCIFORM STABILIZER

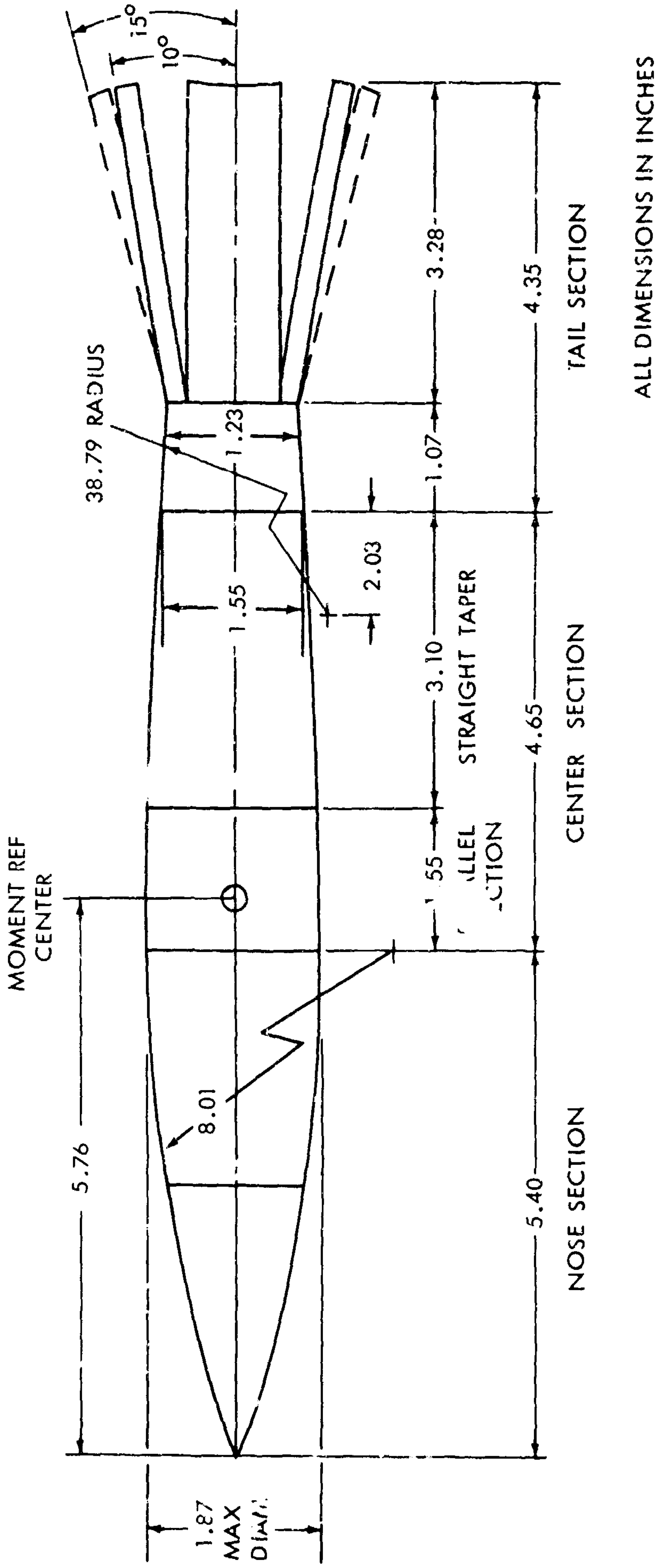


FIG. 3 M823 RESEARCH STORE WITH SPLIT SKIRT STABILIZER

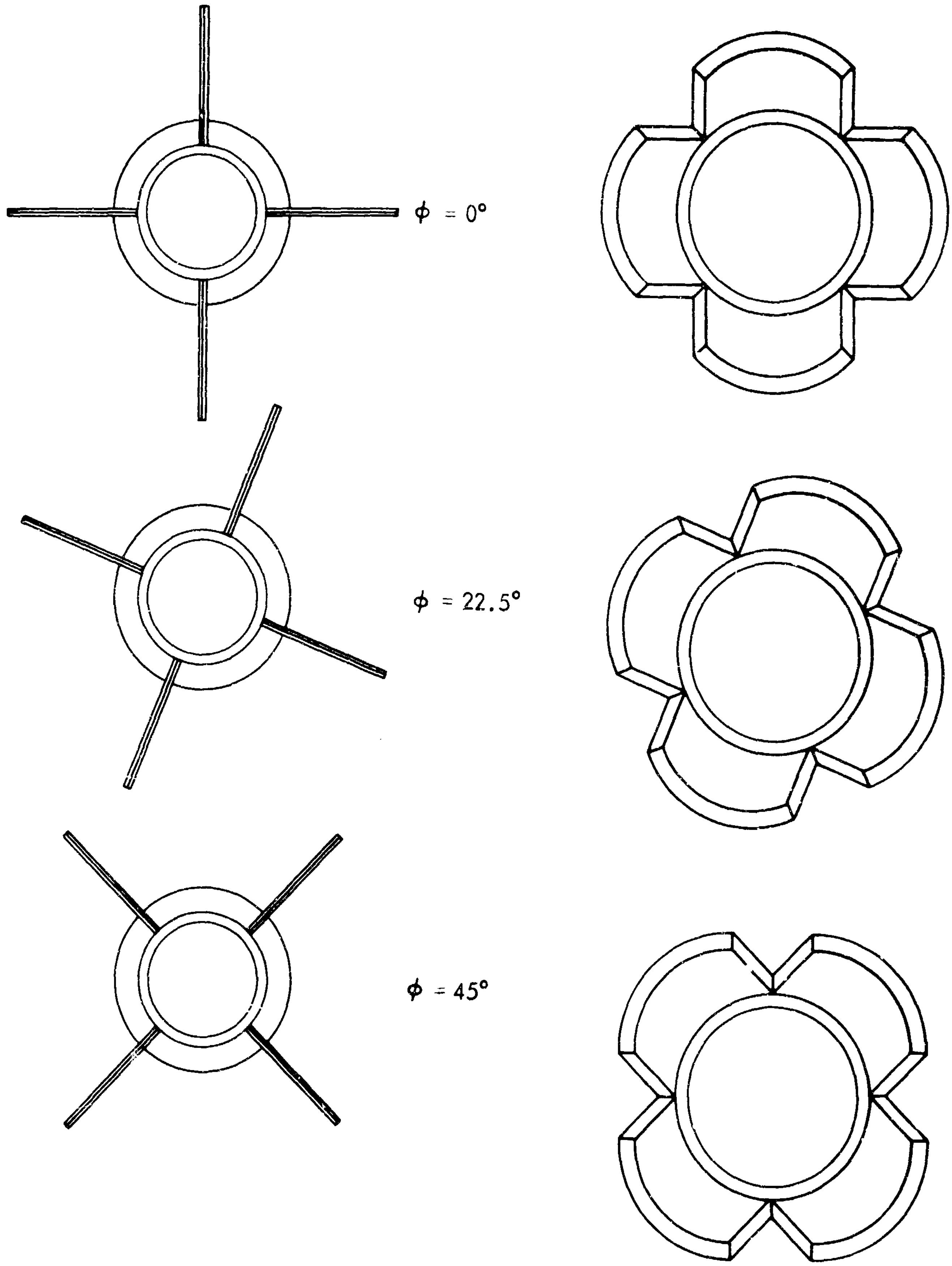


FIG. 4 DEFINITION OF ROLL ORIENTATION

where h, R, T_o and M are altitude, gas constant for air, total temperature and Mach number, respectively. The derivation of equation (1) is an exercise common to many aerodynamic texts, e.g. reference (3).

The Reynolds number variation with Mach number is given by equation (2) below. This expression, taken from reference (4), is

$$\frac{Re}{l} = \frac{P_o M}{\mu_o}\sqrt{\frac{\gamma}{(\gamma-1)C_v T_o}}\left(1+\frac{\gamma-1}{2}M^2\right)^{\frac{2-\gamma}{\gamma-1}}\frac{\left(1+\frac{\gamma-1}{2}M^2\right)^{-1}+\frac{198.6}{T_o}}{1+\frac{198.6}{T_o}} \qquad (2)$$

where Re/l, P_o, μ_o, T_o, γ, C_v and M are Reynolds number per foot, total pressure, dynamic viscosity at stagnation conditions, total temperature, ratio of the specific heats, specific heat at constant volume and tunnel Mach number, respectively. Equations (1) and (2) are presented graphically in Figure 5.

The purpose of the tests was to measure the damping-in-pitch derivative, $C_{m_q} + C_{m_{\dot\alpha}}$. At the Naval Ordnance Laboratory a large amplitude free oscillation technique is used to determine damping in pitch. In this method the model has unrestricted freedom to rotate about a transverse support shaft. Prior to establishing tunnel flow the model is constrained at an angle of attack relative to the horizontal. After flow has been established the model is released and allowed to oscillate freely. Except for a negligible amount of bearing friction, the torque acting on the model is entirely aerodynamic.

Provided that the model is statically and dynamically stable, the angular history of the model is a damped sinusoid. The instantaneous angular deflection of the model is "read" by means of a variable reluctance transducer. Details of the design and operation of this device are given in reference (5). It is sufficient to state that the transducer provides an instantaneous electrical signal which can be related through a calibration procedure to the model's instantaneous angular attitude. The electrical signal from the transducer is sampled 300 times per second. These samples, together with the corresponding time of sample, are recorded digitally on magnetic tape. By means of a calibration record this digital record is converted to a history of the model's angular attitude. It is this angular record that is used in the data reduction procedure.

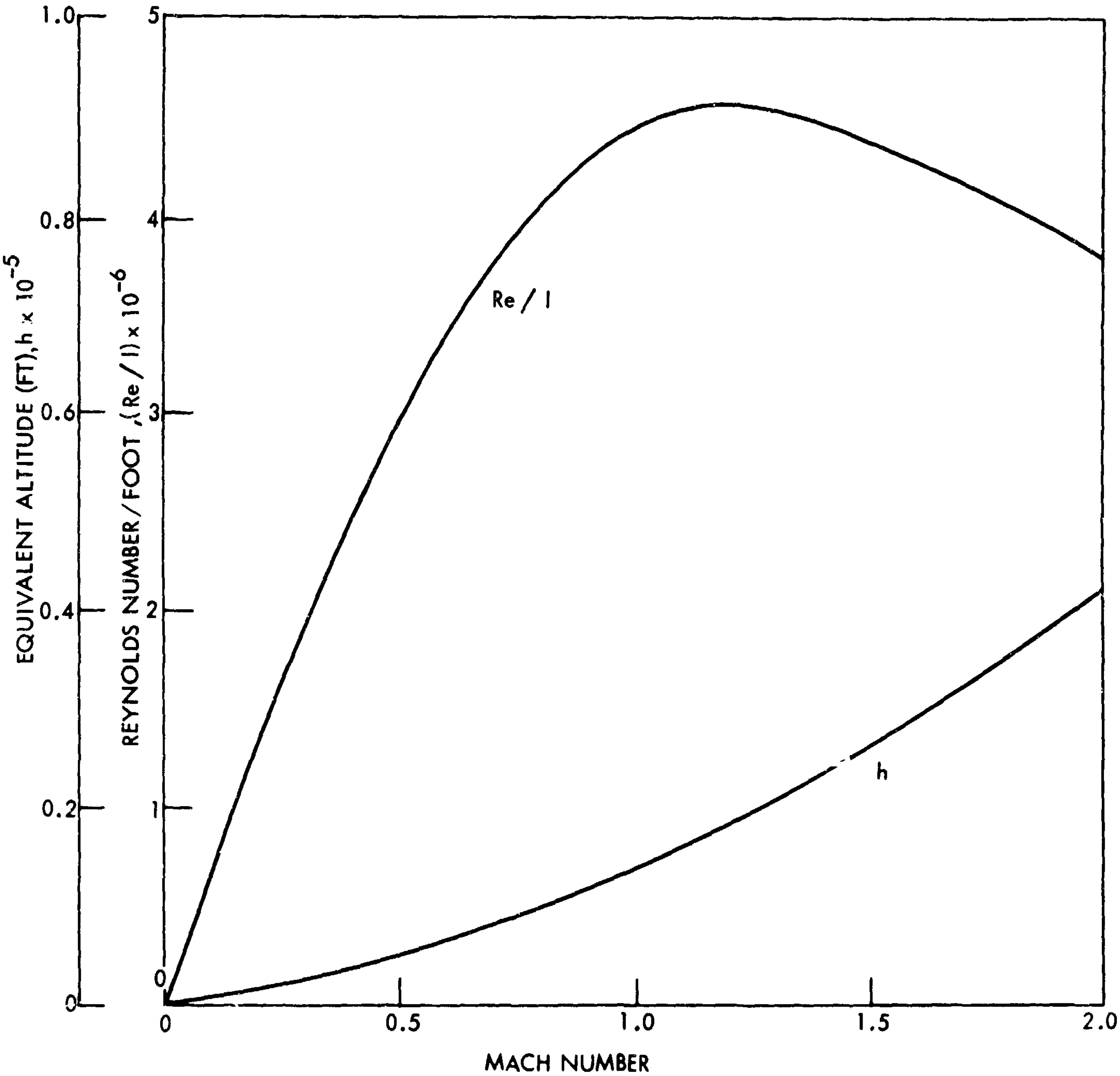


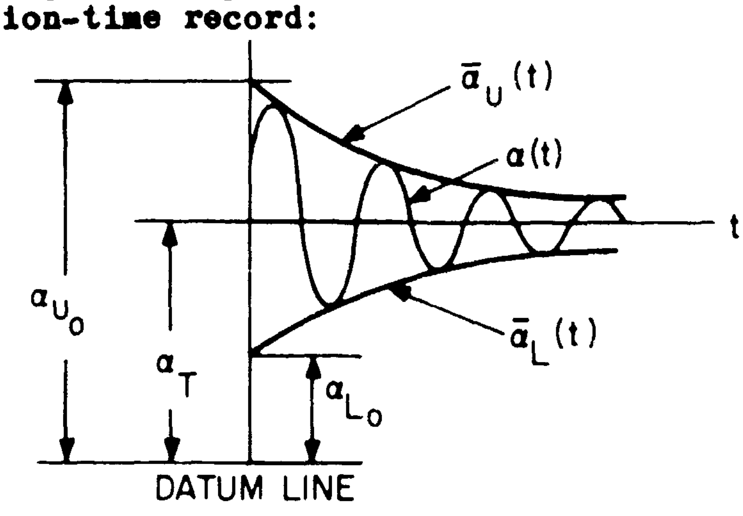
FIG. 5 REYNOLDS NUMBER PER FOOT AND EQUIVALENT ALTITUDE VERSUS MACH NUMBER FOR U.S. NAVAL ORDANCE LABORATORY SUPERSONIC WIND TUNNEL NO. 1

Configurations A and C are shown in the calibration support in Figures 6 and 7, respectively. The calibration record is obtained in quite a straightforward manner. First, the model is locked in a horizontal position. The circular angle index is rotated until "zero" is read on the indicator. Then a lock screw is tightened fixing the index to the model. Next, the angular index, and hence the model, is rotated in 5 degree steps from approximately +80 degrees (model nose up) to about -80 degrees (model nose down). At each 5 degree increment a reading is taken from the transducer. This calibration record is put on magnetic tape for use in data reduction. A calibration record is made before and after each set of runs. A representative calibration record is presented on Figure 8.

DATA REDUCTION

After the transducer calibration record (digital counts versus angle of deflection) and the transducer output (generally, counts versus time) have been recorded on magnetic tape, the data are ready for reduction. The first step is to obtain on magnetic tape a record of model angular attitude versus time. This is accomplished by means of a digital computer program which fits a mathematical function to the calibration record. This fit linearly interpolates between each pair of recorded calibration points. Using this function it is then a fairly straightforward procedure to convert count history to an angular history. The output of this program is a plotting tape which an automatic plotter uses to give a graphical record of angular attitude versus time for each test. Typical pitch damping records are shown for configurations A and C in Figures 9 and 10, respectively. The final step in the data reduction of these records is a manual operation which is based on graphical records. This step yields the damping-in-pitch derivative.

The following sketch points out the salient features of the angular deflection-time record:



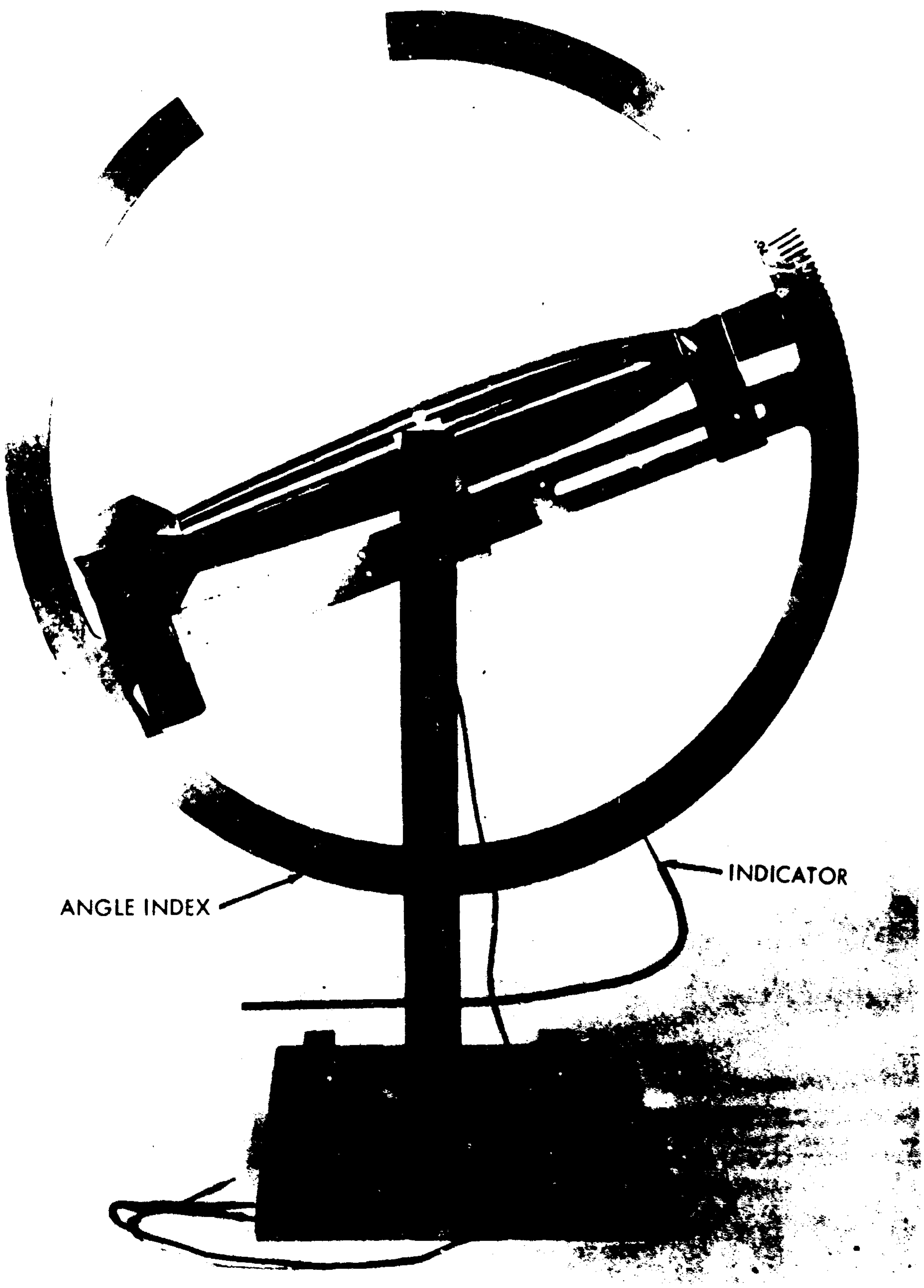


FIG. 6 CONFIGURATION A8O IN PITCH DAMPING CALIBRATION SUPPORT

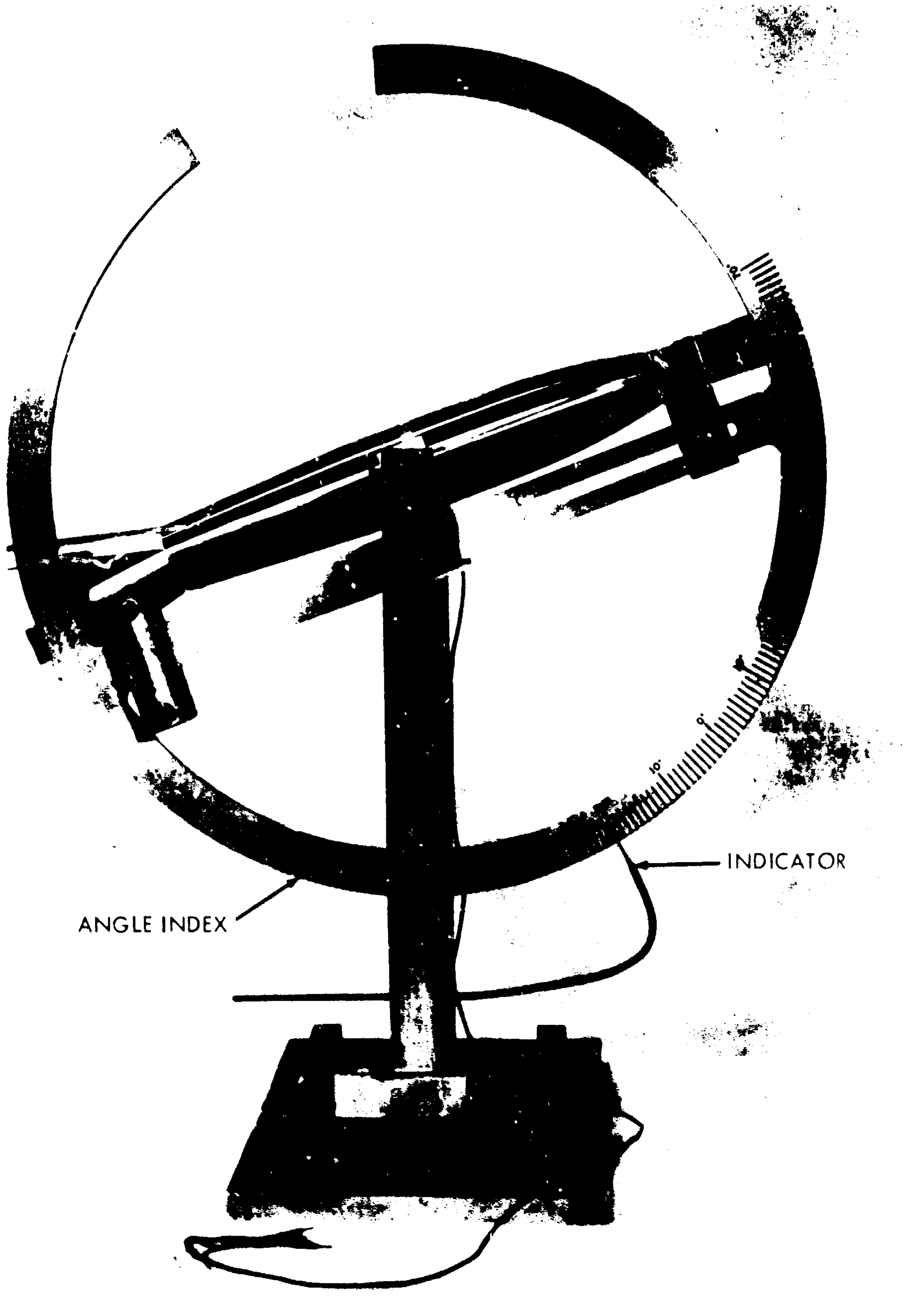


FIG. 7 CONFIGURATION C IN PITCH DAMPING CALIBRATION SUPPORT

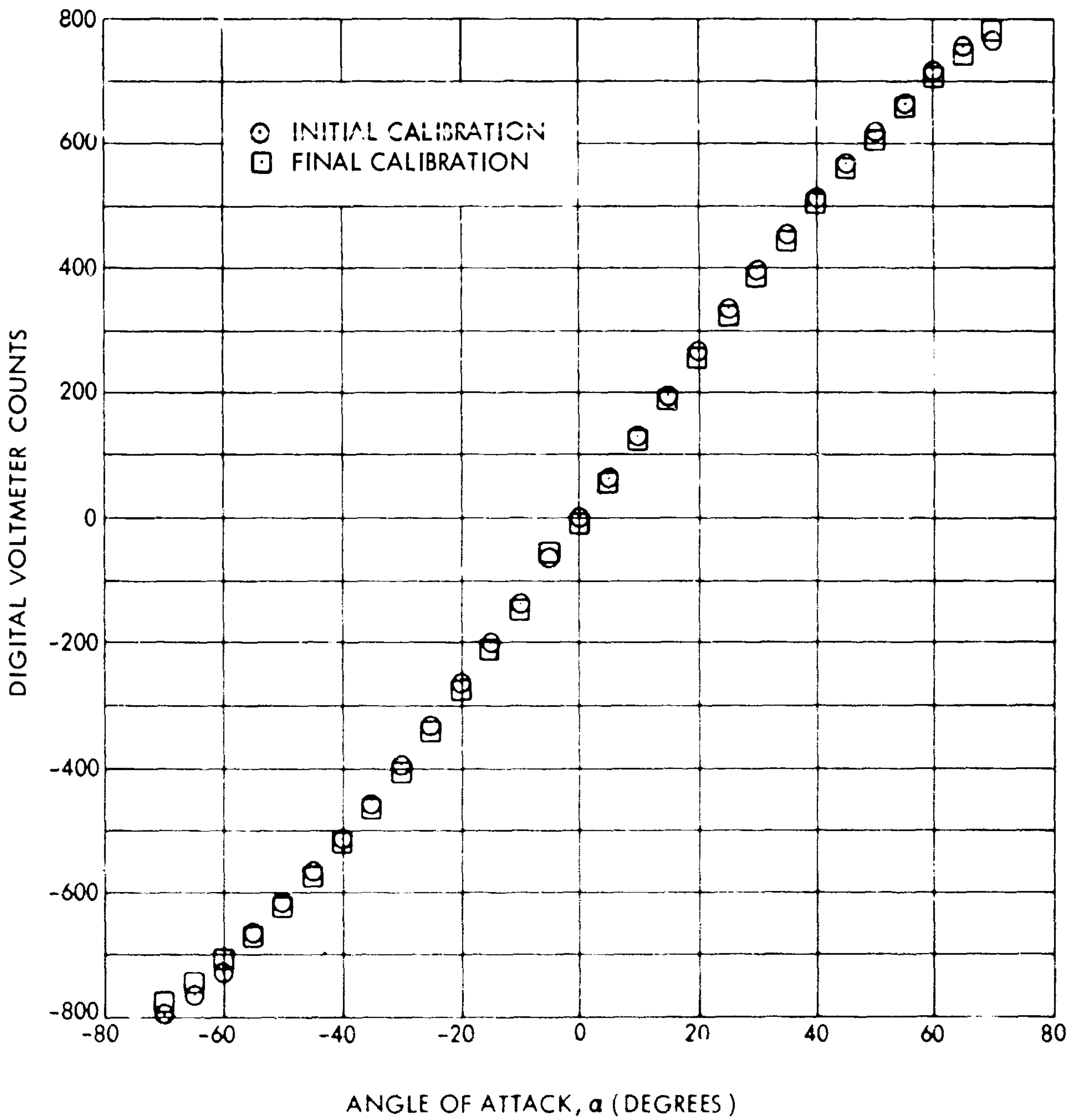


FIG. 8 TYPICAL PITCH DAMPING TRANSDUCER CALIBRATION RECORD

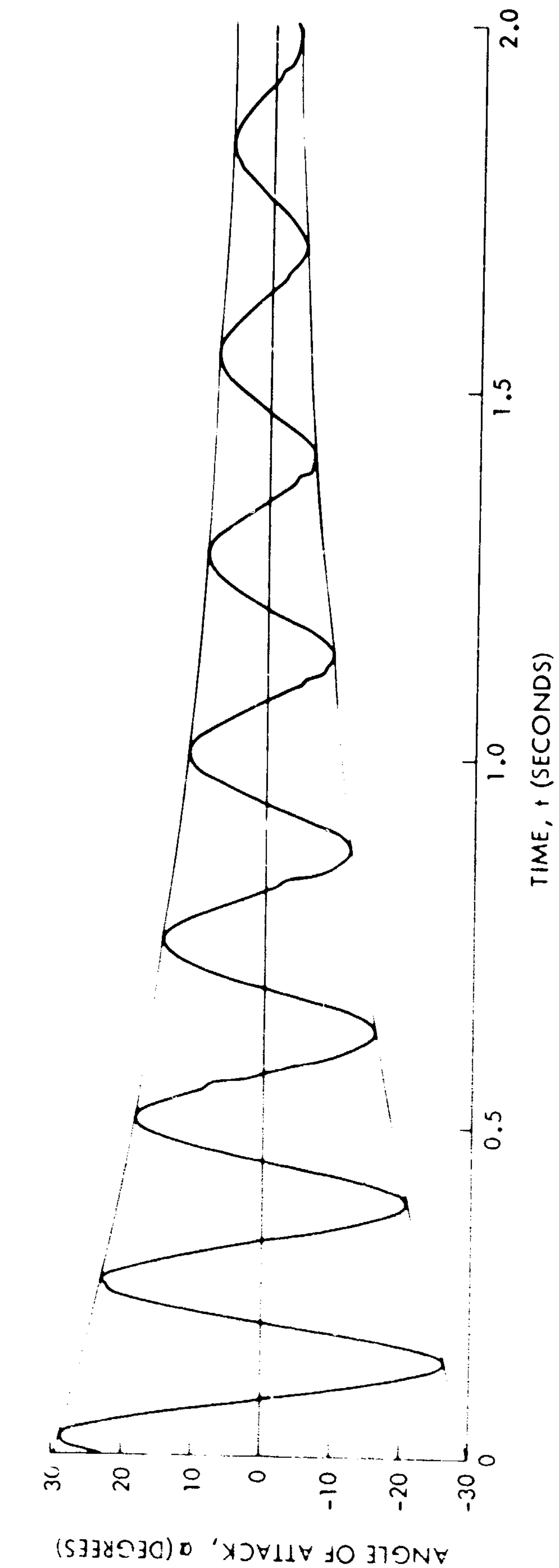


FIG. 9 ANGLE OF ATTACK VERSUS TIME FOR CONFIGURATION A 8 O AT A MACH NUMBER OF 0.65 AND A ROLL ANGLE OF 45.0 DEGREES

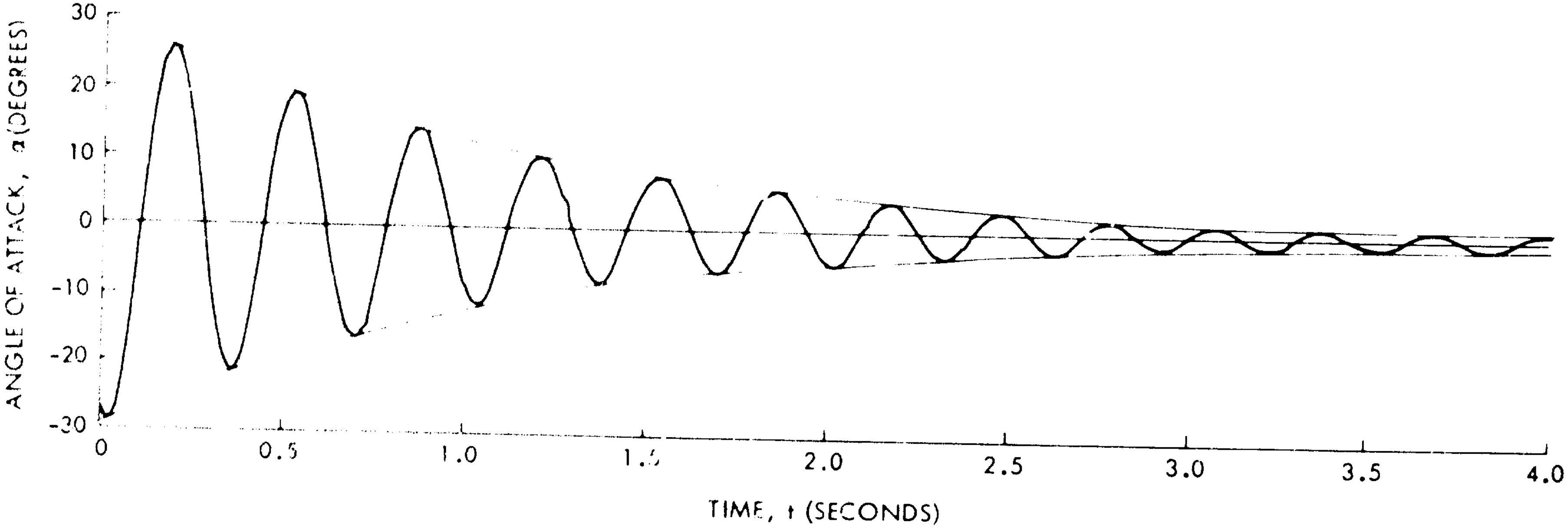


FIG.10 ANGLE OF ATTACK VERSUS TIME FOR CONFIGURATION C AT A MACH NUMBER OF 0.85 AND A ROLL ANGLE OF 22.5 DEGREES

Here, the symbol α refers to the instantaneous angle of attack of the model. The subscript T refers to trim conditions. In this case trim refers to the steady state angle of attack above some arbitrary reference datum. The barred quantities refer to the envelope of the damped oscillatory motion, and the subscripts U and L refer to the upper and lower envelopes, respectively. In order to obtain the damping-in-pitch derivative, $C_{m_q} + C_{m_{\dot{\alpha}}}$, it is necessary to regard the graphical records as solutions to the second order differential equation,

$$\ddot{\alpha} - \left[\frac{\partial M/\partial q + \partial M/\partial \dot{\alpha}}{I_y}\right]\dot{\alpha} - \left[\frac{\partial M/\partial \alpha}{I_y}\right]\alpha = -\left[\frac{\partial M/\partial \alpha}{I_y}\right]\alpha_T \tag{3}$$

where the bracketed quantities are assumed to be constants. Equation (3) may be rewritten using the following aerodynamic coefficients:

$$\frac{\partial M}{\partial q} = \frac{\partial C_m}{\partial\left(\frac{qd}{2V}\right)}\,\frac{\partial\left(\frac{qd}{2V}\right)}{\partial q}QSd = C_{m_q}\frac{QSd^2}{2V} \tag{4a}$$

$$\frac{\partial M}{\partial \dot{\alpha}} = \frac{\partial C_m}{\partial\left(\frac{\dot{\alpha}d}{2V}\right)}\,\frac{\partial\left(\frac{\dot{\alpha}d}{2V}\right)}{\partial \dot{\alpha}}QSd = C_{m_{\dot{\alpha}}}\frac{QSd^2}{2V} \tag{4b}$$

$$\frac{\partial M}{\partial \alpha} = \frac{\partial C_m}{\partial \alpha}QSd = C_{m_\alpha}QSd \tag{4c}$$

Using the coefficients defined in equations (4), equation (3) becomes

$$\ddot{\alpha} - \left[\frac{(C_{m_q} + C_{m_{\dot{\alpha}}})QSd^2}{2VI_y}\right]\dot{\alpha} - \left[\frac{C_{m_\alpha}QSd}{I_y}\right]\alpha = -\left[\frac{C_{m_\alpha}QSd}{I_y}\right]\alpha_T\,. \tag{5}$$

For light damping (damping less than 10 percent of critical), the solution of equation (5) can be accurately approximated by either of the following expressions:

$$\alpha = \alpha_T + (\bar{\alpha}_U - \alpha_T)\,\mathrm{Cos}\left\{\sqrt{-\frac{C_{m_\alpha}QSd}{I_y}}\;t\right\} \tag{6a}$$

or

$$\alpha = \alpha_T - (\alpha_T - \bar{\alpha}_L) \operatorname{Cos}\left\{\sqrt{-\frac{C_{m_\alpha} QSd}{I_y}}\ t\right\} \tag{6b}$$

where

$$\bar{\alpha}_U = (\alpha_{U_o} - \alpha_T)\, e^{\lambda t} + \alpha_T \tag{7a}$$

is the upper envelope of the oscillations,

$$\bar{\alpha}_L = \alpha_T - (\alpha_T - \alpha_{L_o})\, e^{\lambda t} \tag{7b}$$

is the lower envelope, and α_T is the trim angle of attack.
The logarithmic decrement, λ, is obtained from equation (5) and may be expressed as,

$$\lambda = \frac{(C_{m_q} + C_{m_{\dot{\alpha}}})QSd^2}{4VI_y} \quad . \tag{8}$$

If equation (7b) is subtracted from equation (7a) and the resulting expression is solved for the logarithmic decrement, λ, the result is

$$\lambda = \frac{1}{t}\, \ell n\left(\frac{\alpha_U - \alpha_L}{\alpha_{U_o} - \alpha_{L_o}}\right) \tag{9}$$

where t is the time at which α_U and α_L are measured.

Finally, if the decrement, λ, is replaced by its equivalent from equation (8), then equation (9) may be rewritten as,

$$C_{m_q} + C_{m_{\dot{\alpha}}} = \left(\frac{32I_y}{\rho V \pi d^4}\right) \frac{1}{t}\, \ell n \left(\frac{\alpha_U - \alpha_L}{\alpha_{U_o} - \alpha_{L_o}}\right) \quad , \tag{10}$$

where S (the reference area) and Q (the dynamic pressure) have been replaced by $\pi d^2/4$ and $\rho V^2/2$, respectively.

DISCUSSION OF RESULTS

The results of the wind tunnel pitch damping tests are presented in Figures 11 through 20. Figures 11, 12 and 13 are plotted from the measurements made on configuration Aδ0; Figure 14, from measurements made on configuration Bδ4; Figures 15, 16 and 17, from measurements made on configuration C; and Figures 18, 19 and 20, on configuration E. The data presented are the damping-in-pitch derivative as a function of free-stream Mach number.

Configuration A was tested statically with fins canted at 0, 2 and 4 degrees. A preliminary set of pitch damping measurements indicated that within the data scatter there was no appreciable effect of fin cant upon damping. Therefore, pitch damping measurements are presented only for the Aδ0 configuration or configuration A with zero fin cant.

Figures 11, 12 and 13 present the damping-in-pitch derivative as a function of Mach number at roll angles of 0, 22.5 and 45.0 degrees, respectively.

The pitch damping effectiveness of the free-spinning cruciform stabilizer (configuration B) is shown in Figure 14. Again, no effect due to fin cant could be discerned; thus only the configuration with a four degree fin cant (configuration Bδ4) was examined in detail.

For configurations A and B the moment reference center was at the midpoint of the body along its longitudinal axis. This is the same reference point as was used for the reduction of the static data (see reference (1)).

For the split-skirt configurations it was found from static measurements that the normal force center of pressure was in the vicinity of the body midpoint. Since using this as a pivoting axis would result in the pitch damping model being unstable, it was decided to place the axis of rotation at a point 40 percent aft of the model's nose. Thus the moment reference center, or the axis of rotation, is at the 50 percent body axis point for configurations A and B and at the 40 percent body position for configurations C and E.

The pitch damping moment measurements for configuration C at roll angles of 0, 22.5 and 45.0 degrees are presented in Figures 15, 16 and 17, respectively. Similar measurements for configuration E are presented in Figures 18, 19 and 20. For all cases, it should be noted that these data show only a small variation in pitch damping with either Mach number or roll angle.

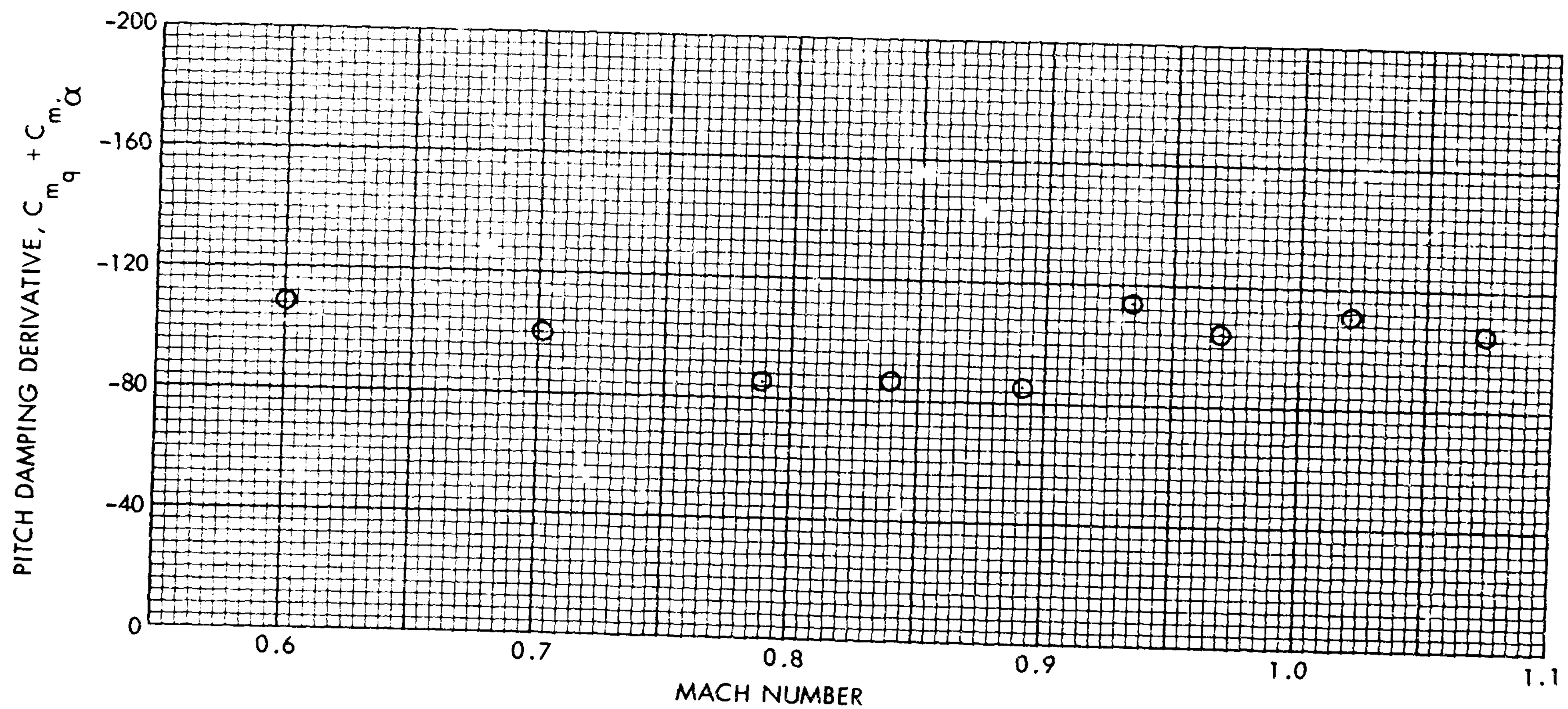


FIG. 11 PITCH DAMPING DERIVATIVE VERSUS MACH NUMBER FOR CONFIGURATION AδO AT A ROLL ANGLE OF ϕ = 0 DEGREES

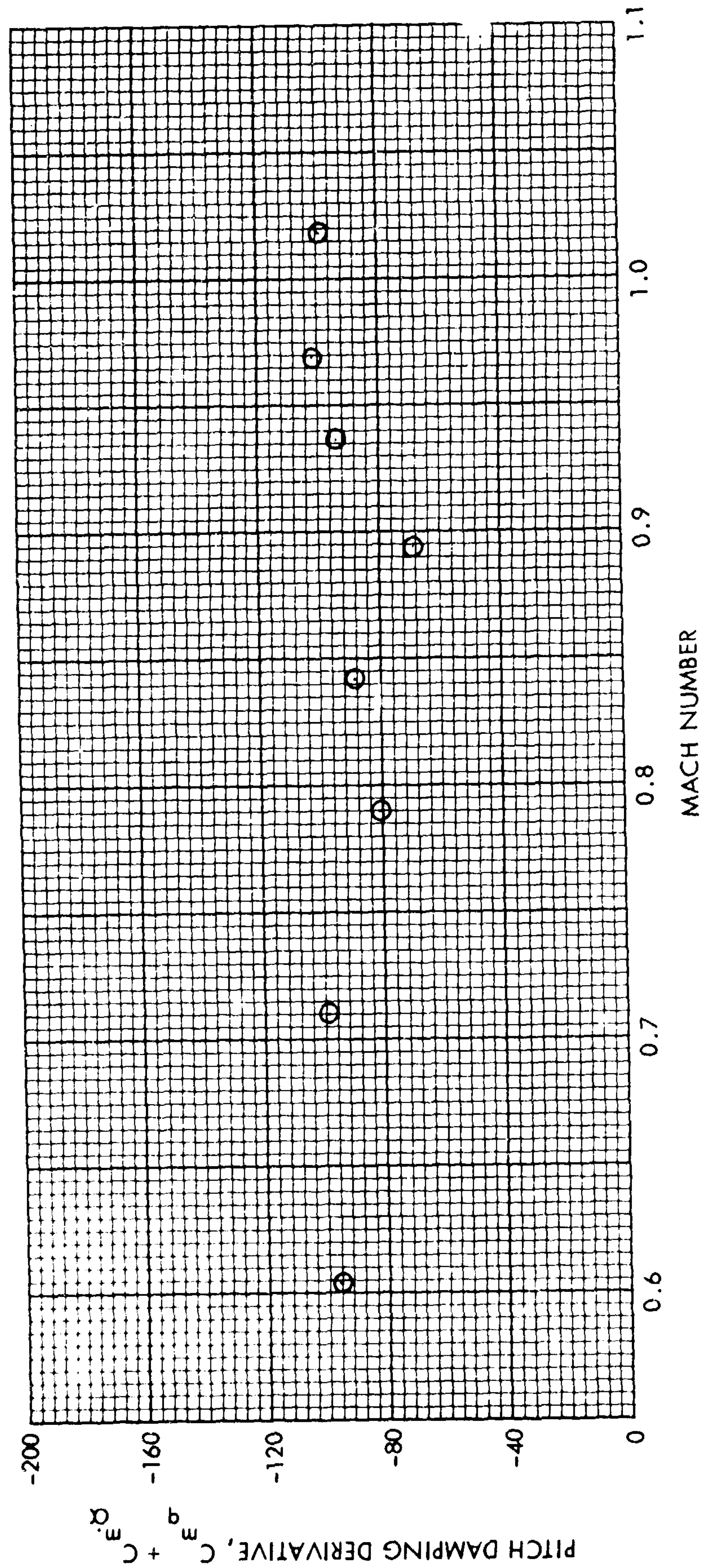


FIG. 12 PITCH DAMPING DERIVATIVE VERSUS MACH NUMBER FOR CONFIGURATION AδO AT A ROLL ANGLE OF $\phi = 22.5$ DEGREES

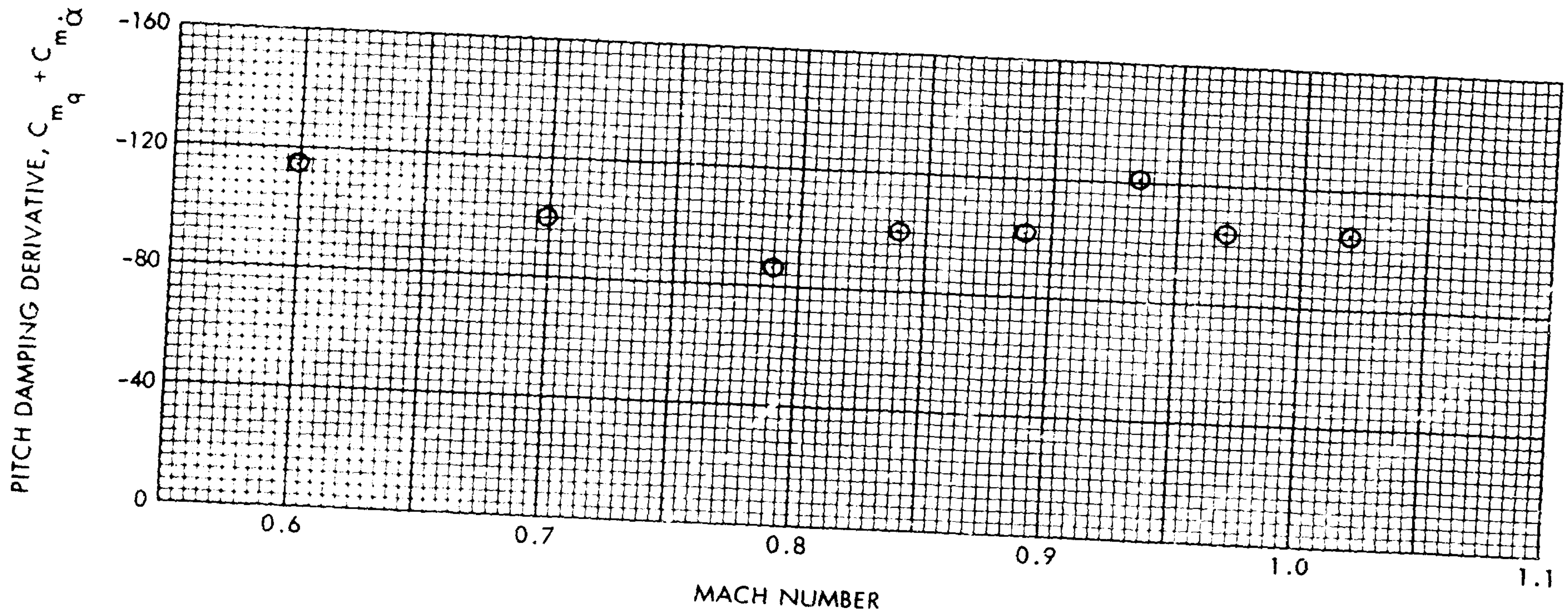


FIG. 13 PITCH DAMPING DERIVATIVE VERSUS MACH NUMBER FOR CONFIGURATION AδO AT A ROLL ANGLE OF ϕ = 45 DEGREES

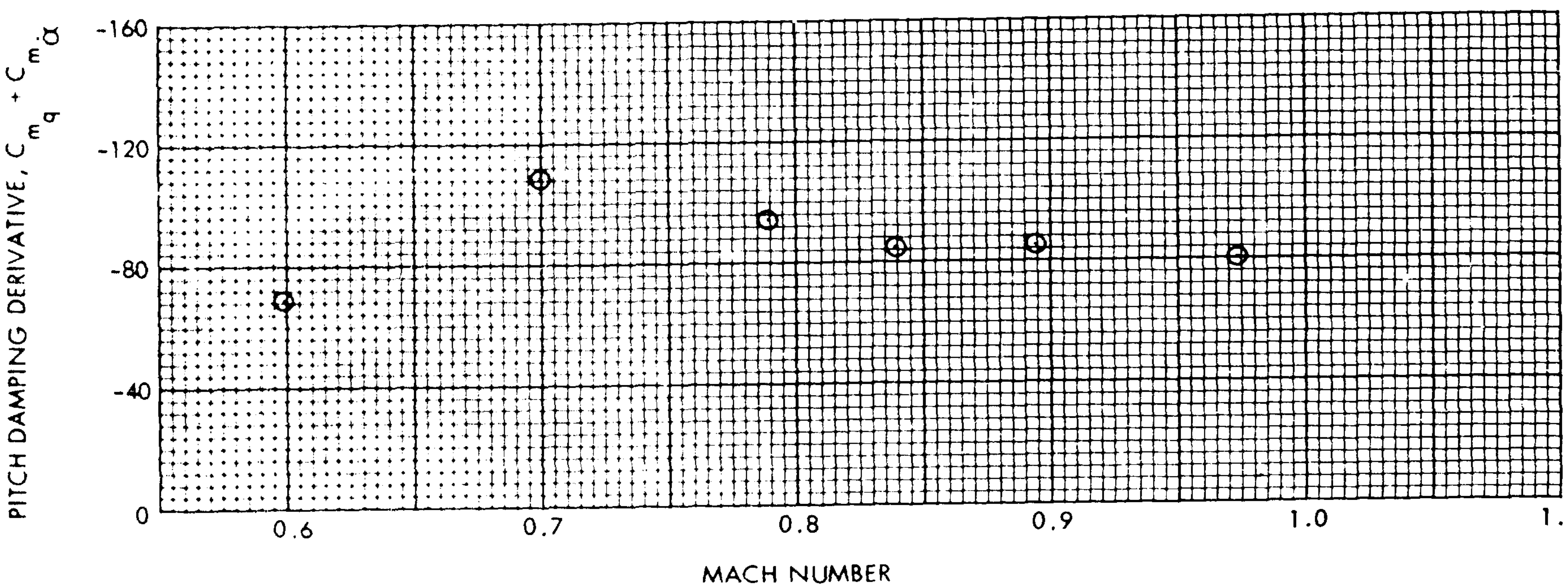


FIG. 14 PITCH DAMPING DERIVATIVE VERSUS MACH NUMBER FOR CONFIGURATION Bδ4 AT A ROLL ANGLE OF Φ = 22.5 DEGREES

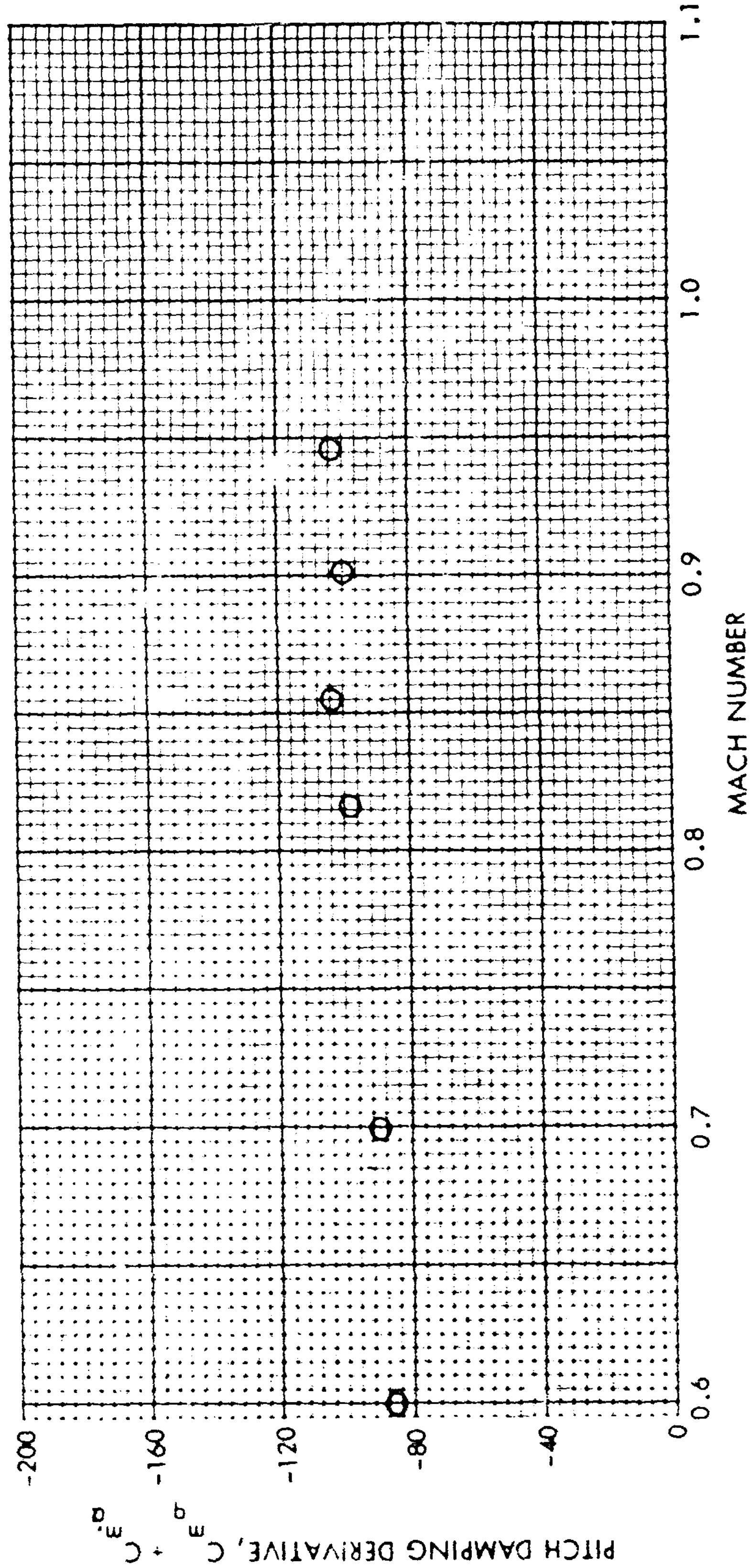


FIG. 15 PITCH DAMPING DERIVATIVE VERSUS MACH NUMBER FOR CONFIGURATION C AT A ROLL ANGLE OF ϕ = O DEGREES

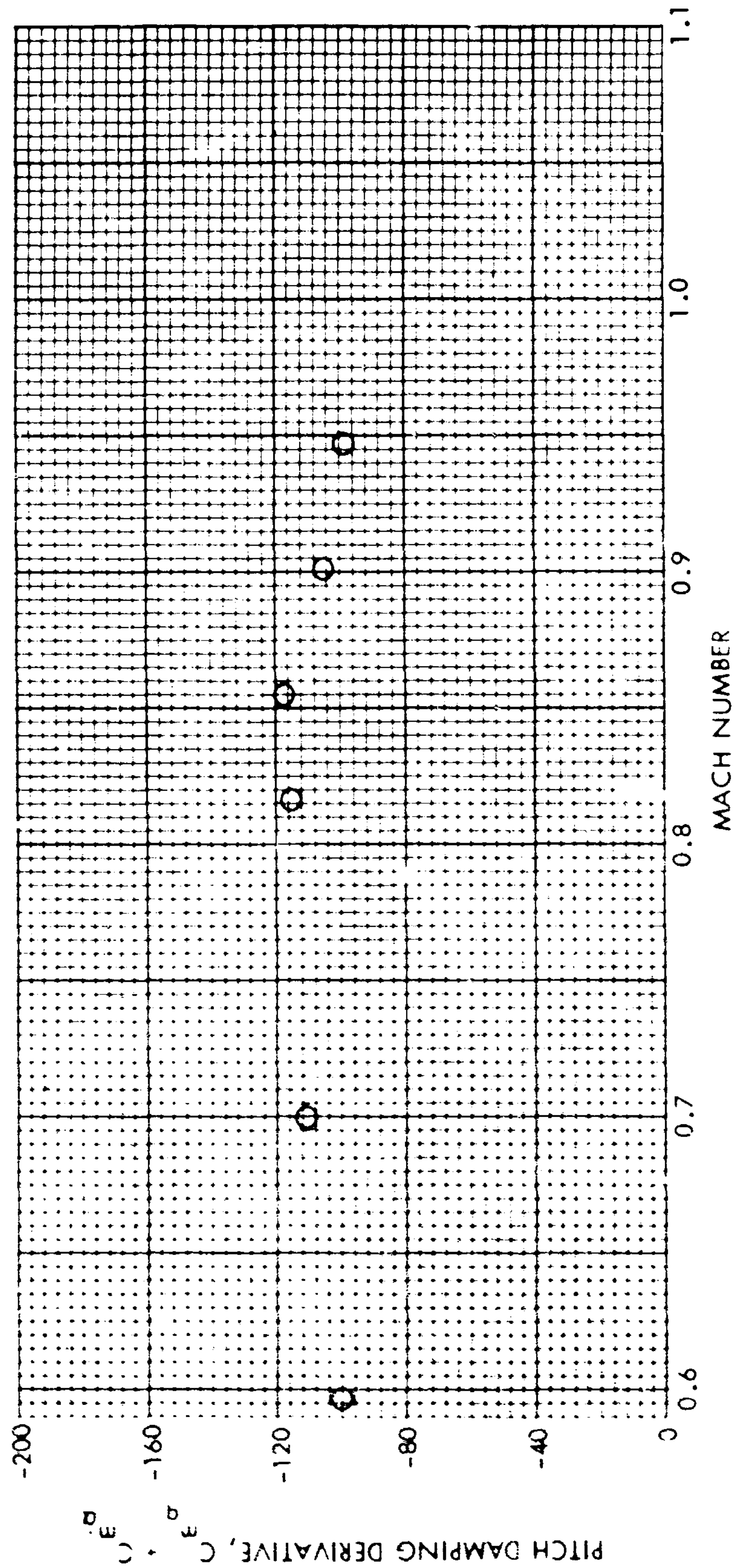


FIG. 16 PITCH DAMPING DERIVATIVE VERSUS MACH NUMBER FOR CONFIGURATION C AT A ROLL ANGLE OF ϕ = 22.5 DEGREES

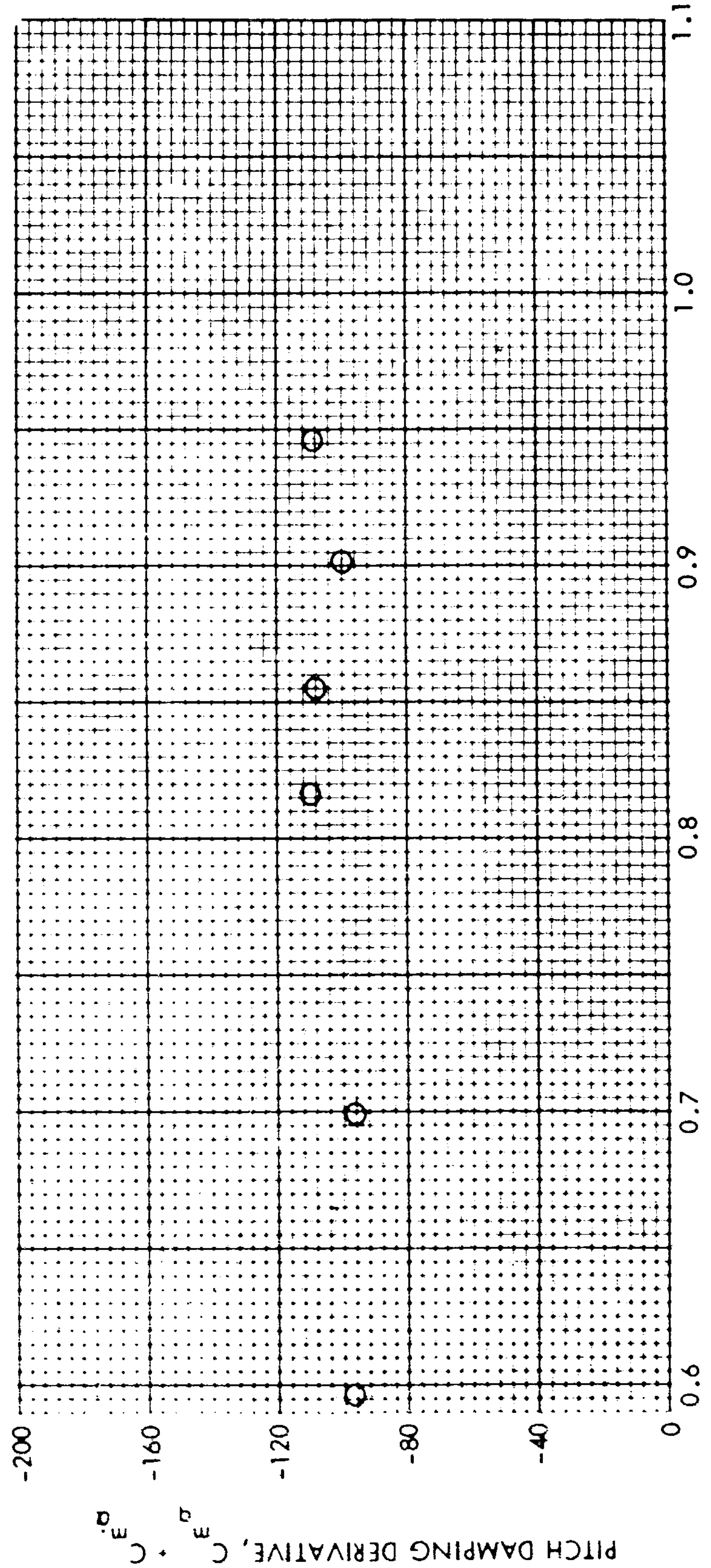


FIG. 17 PITCH DAMPING DERIVATIVE VERSUS MACH NUMBER FOR CONFIGURATION C AT A ROLL ANGLE OF ϕ = 45 DEGREES

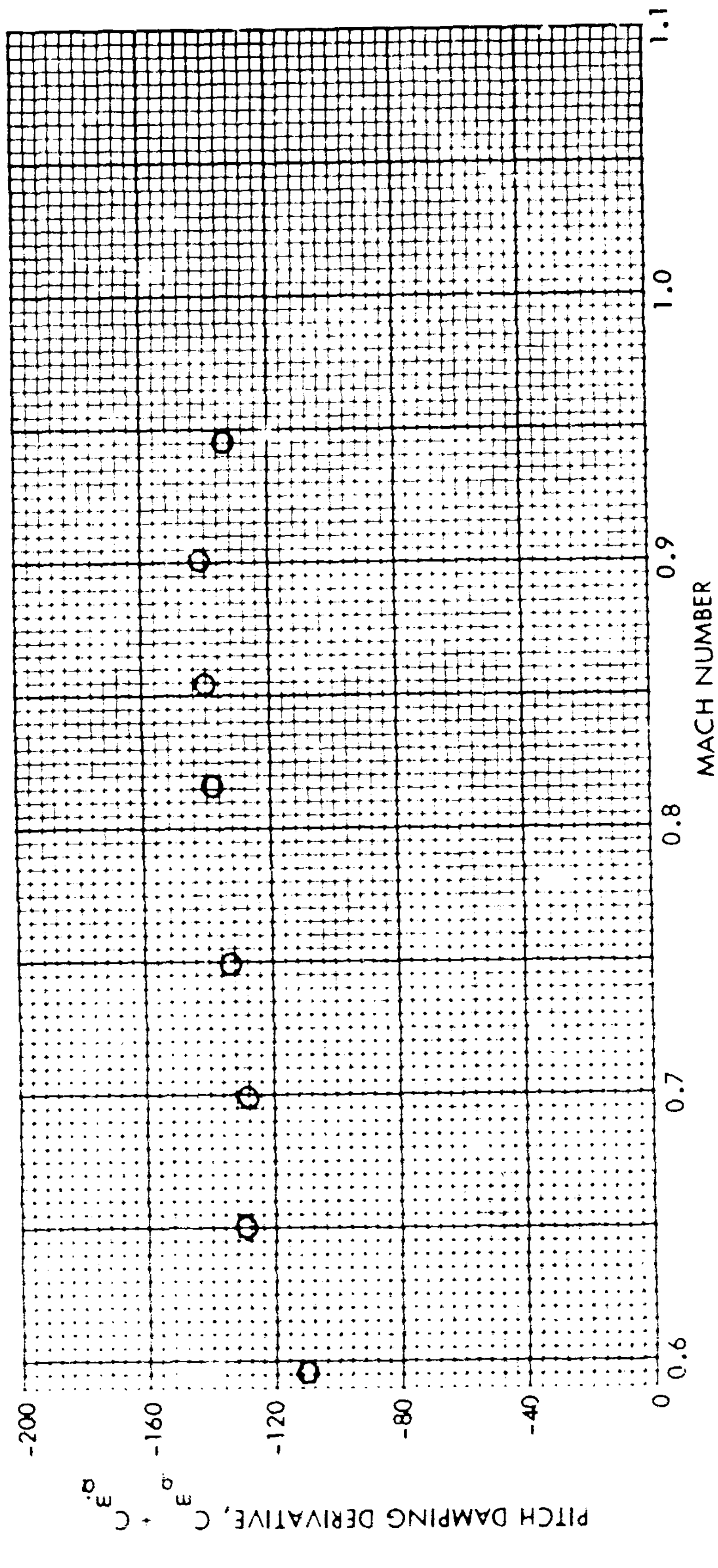


FIG. 18 PITCH DAMPING DERIVATIVE VERSUS MACH NUMBER FOR CONFIGURATION E AT A ROLL ANGLE OF ϕ = O DEGREES

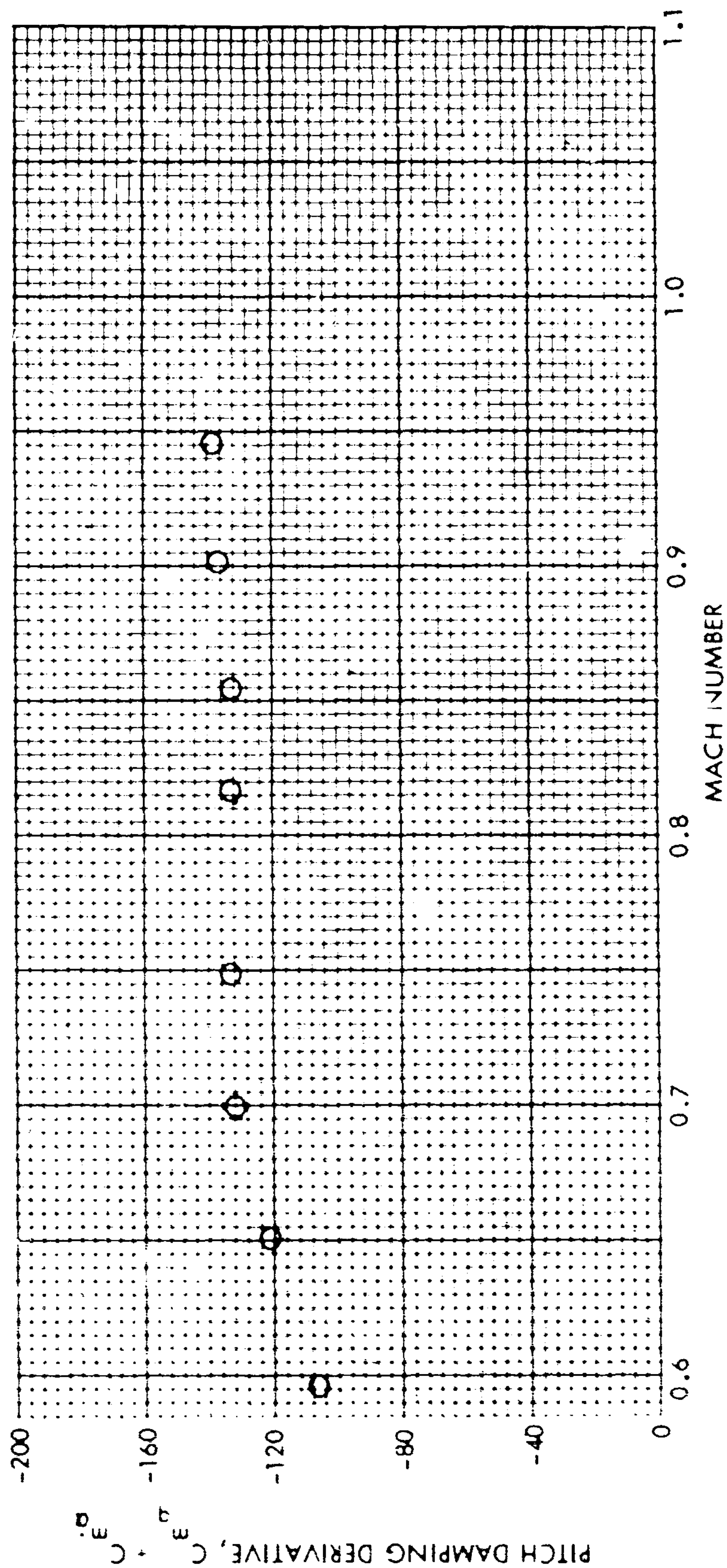


FIG. 19 PITCH DAMPING DERIVATIVE VERSUS MACH NUMBER FOR CONFIGURATION E AT A ROLL ANGLE OF ϕ = 22.5 DEGREES

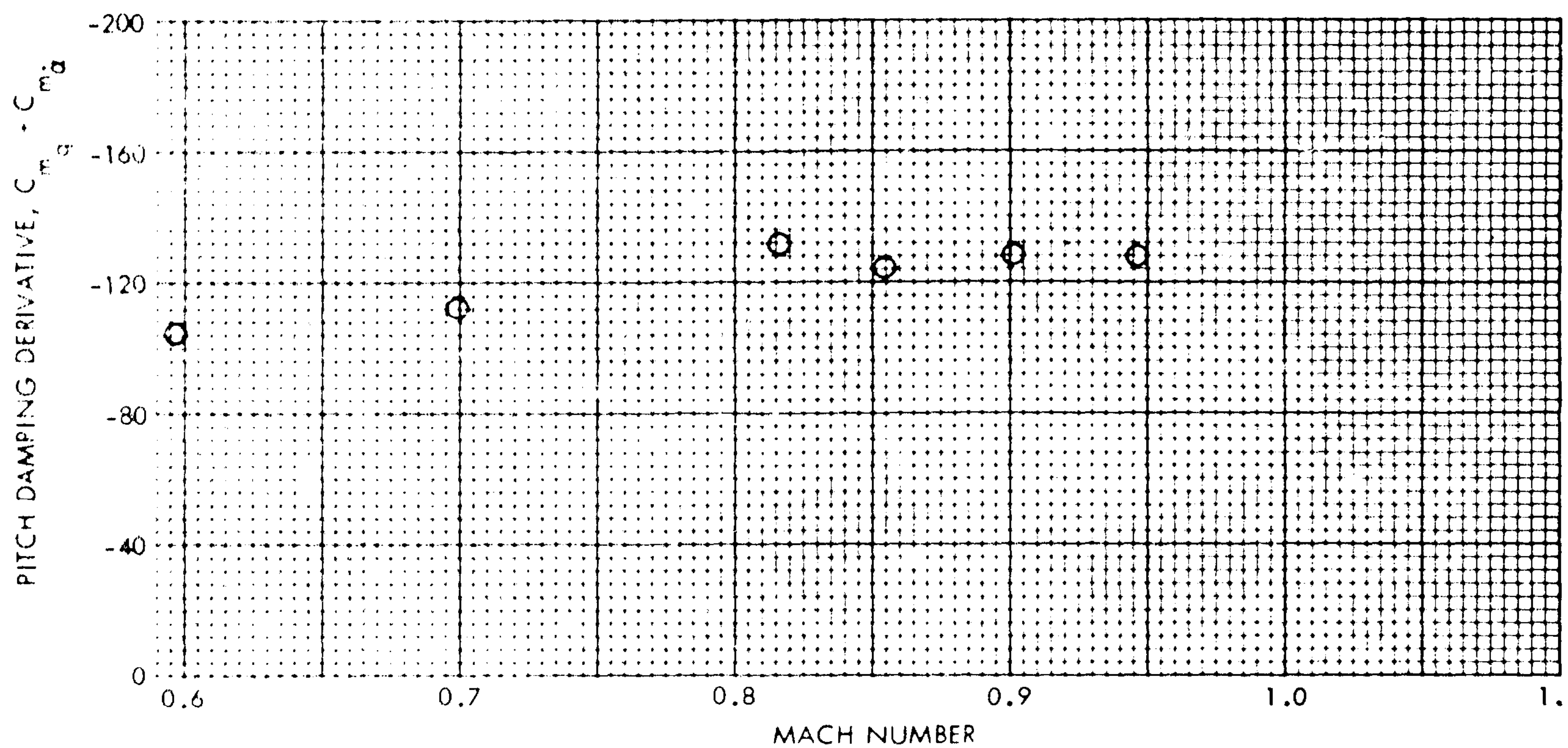


FIG.20 PITCH DAMPING DERIVATIVE VERSUS MACH NUMBER FOR CONFIGURATION E AT A ROLL ANGLE OF ϕ 45 DEGREES

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